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(54) Sterilizing with hydrogen peroxide and plasma.

(57) A process for plasma sterilization comprising exposing an article to be sterilized to pretreatment with hydrogen peroxide, and optionally a peracid antimicrobial agent, and to a plasma generated from gases. The gases can be selected from the group consisting essentially of argon, helium, nitrogen, oxygen, hydrogen and mixtures thereof; and the exposure to the plasma can be carried out at a pressure of from 0.1 to 10 torr and a chamber temperature of less than 80° C. The peracid antimicrobial agent can be a member selected from the group consisting of saturated and unsaturated peralkanoic acids having from 1 to 2 carbon atoms and halogenated derivatives thereof and is preferably peracetic acid. The article is preferably treated with plasma generated in a plasma generator separate from the sterilizing chamber.

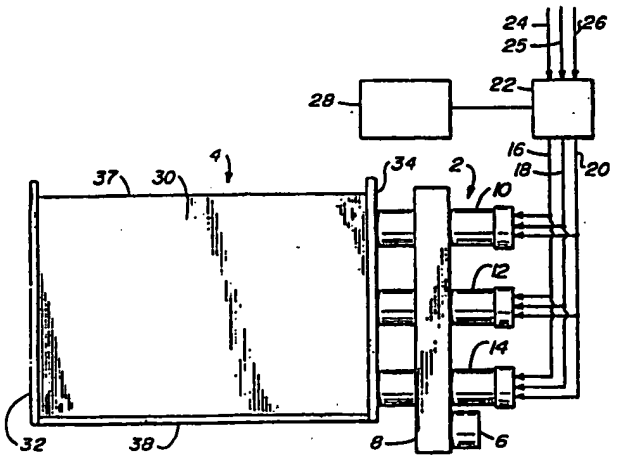

FIG._1

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course of producing high sporicidal kill rates. As a result, they do not achieve the necessary goal of providing an all purpose, one hundred percent effective sterilizing system and process.

Summary and Objects of the Invention

One embodiment of the process for plasma sterilization of this invention comprises treating an article to be sterilized with hydrogen peroxide and a peracid antimicrobial agent for a time sufficient to expose all surfaces of the article to the hydrogen peroxide and peracid, and then exposing the article to a gas plasma. The gas plasma is generated from gases selected from the group consisting essentially of argon, helium, nitrogen, oxygen, hydrogen and mixtures thereof. The exposure to the plasma is carried out at a pressure of from 0.1 to 10 torr and a chamber temperature of less than 80° C for a time period sufficient to effect sterilization. The peracid antimicrobial agent is a member selected from the group consisting of saturated and unsaturated peralkanoic acids having from 1 to 8 carbon atoms and halogenated derivatives thereof and is preferably peracetic acid vapor.

Optimally, the plasma is produced in a plasma generator and is fed therefrom to a sterilizing chamber. The article to be sterilized is located in the sterilizing chamber, and the peracid antimicrobial agent vapor is introduced into the sterilizing chamber to expose the article located therein to said pretreatment. After said pretreatment, the pressure in the sterilizing chamber is reduced to a pressure not exceeding 10 torr, and the plasma is thereafter introduced into the sterilizing chamber.

Preferably, the plasma is generated from a gas mixture consisting essentially of argon, helium, nitrogen or mixtures thereof; from 1 to 21 (v/v) % oxygen; and from 1 to 20 (v/v) % hydrogen and optimally a gas mixture containing from 1 to 10 % (v/v) oxygen and from 3 to 7 % (v/v) hydrogen.

This process is suitable for sterilizing an article enclosed in a porous container, the container being surrounded by the gas plasma during the treatment, even when the porous container comprises a carbohydrate composition.

An alternative embodiment of the process of this invention for plasma sterilization comprises the steps of (a) pretreating an article to be sterilized with hydrogen peroxide for a time sufficient to expose all surfaces of the article to the hydrogen peroxide, and (b) producing gas plasma in a plasma generator from gases selected from the group consisting essentially of argon, helium, nitrogen, oxygen, hydrogen and mixtures thereof, and (c) feeding the gas plasma to a sterilizing chamber containing the pretreated article at a pressure of from 0.1 to 10 torr and a chamber temperature of less than 80° C for a time period sufficient to kill organisms present on the article.

Preferably, the article is pretreated with hydrogen peroxide vapor in the sterilizing chamber for at least 5 minutes. After said pretreatment, the pressure in the sterilizing chamber is reduced to a pressure not exceeding 10 torr, and the plasma is thereafter introduced into the sterilizing chamber.

The object of this invention is to provide a process which achieves one hundred percent spore skill rates with all types of articles used in the health care environment, including metallic articles and articles contained in porous sterile packages including cellulosic materials.

It is another object of this invention to provide a low pressure, low temperature plasma sterilization process which is one hundred percent effective for sterilizing packaged articles without destroying the integrity of the packages.

Brief Description of the Drawings

Fig. 1 is a top view of a plasma sterilizer of this invention.

Fig. 2 is a front view of the plasma sterilizer embodiment of Fig. 1.

Fig. 3 is a cross-sectional view of the plasma sterilizer embodiment of Fig. 1 and Fig. 2, taken along the line 3-3 in Fig. 2.

Fig. 4 is a cross-sectional view of the plasma sterilizer embodiment of Fig. 3, taken along the line 4-4.

Fig. 5 is a cross-sectional view of tube 54 taken along line 5-5 in Fig. 3.

Fig. 6 is a cross-sectional view of tube 58 taken along line 6-6 in Fig. 3.

Fig. 7 is a cross-sectional view of tube 56 taken along line 7-7 in Fig. 3.

Detailed Description of the Invention

Hospitals originally relied on disinfectants and steam autoclaves for sterilizing implements. In more recent years, ethylene oxide gas sterilization has made possible the sterilization of packaged articles, drugs and medical supplies, and hospital systems are highly dependent upon these procedures. Ethylene oxide is now known to be a dangerous carcinogen, however, and a number of new state laws protecting worker safety and the environment are precluding further use of ethylene oxide sterilizers in hospital nvironments.

Numerous gas plasma sterilizers using a wide variety of gases have been d scribed in the literature. A few have been commercially produced. On system described in U.S. Patent 4,643,876, for xample, pretreats the articl to be sterilized with hydrogen peroxide before it is placed in the elec-

ditions would result in a doubling of the exponent of the probability term, for example 10^{-6} would become 10^{-12}.

The process of this invention comprises exposing an article to be sterilized to pretreatment with hydrogen peroxide and optionally with a peracid antimicrobial agent, and then to a gas plasma. The hydrogen peroxide treatment can be effected by contacting the article with an aqueous solution of hydrogen peroxide or with hydrogen peroxide vapors. Aqueous solutions containing from 1 to 10 wt.% and preferably from 2 to 8 wt.% hydrogen peroxide are suitable for direct solution contact with the article. Solution contact times of from 5 to 10 minutes are usually sufficient to insure complete contact of the hydrogen peroxide and the surfaces of the article.

Preferably, the article is contacted with hydrogen peroxide vapors containing from 1 to 10 % (v/v) and preferably from 2 to 8 % (v/v) hydrogen peroxide vapor. The optimal vapor pretreatment involves contacting the article to be sterilized with hydrogen peroxide vapor in the sterilizing chamber. A contact time of from 5 to 15 minutes is usually sufficient to insure contact of the entire surface of a packaged article with the hydrogen peroxide vapor.

The pretreatment with peracid shall be described hereinafter with respect to peracetic acid for purposes of clarity of presentation and not by way of limitation, and all suitable peracid antimicrobial agents are intended to be included within the scope of this invention.

The peracid treatment can be effected by contact of the article with antimicrobial concentrations of the peracid in aqueous solution or peracid vapor. Preferably, the peracid pretreatment is carried out by exposing the article to be sterilized to peracid vapor having a concentration of from 1 to 35 % (v/v) peracid and preferably from 6 to 12 % (v/v) peracid for a time sufficient to permit contact of the vapor with all surfaces of the article being sterilized, packaged or unpackaged. The exposure time is preferably from 5 to 15 minutes with packaged articles. The peracid exposure can be carried out at a temperature of from 20 to 80 °C and preferably from 40 to 60 °C.

Some peracids in certain concentrations are explosive at elevated temperatures. For this reason, peracetic acid is usually transported and stored in aqueous solutions having less than 35 wt.% peracetic acid. The peracetic acid solution is easily vaporized, and effective treatment of articles, according to this invention, can be achieved by exposing the articles to peracetic acid vapors at pressures in the range of from 1 to 18 torr, the lower pressure limit being the lower range limit of the effective concentration of the peracetic acid.

In the preferred process of this invention, the peracid pretreatment is carried out with vapor introduced into the sterilizing chamber, and the article is pretreated with the peracid prior to exposing the article to the plasma. Suitable plasma sterilizing systems for carrying out the process of this invention are described in co-pending, commonly assigned United States Patent Application Serial No. 07/475,602 filed February 6, 1990, the entire contents of which are hereby incorporated by reference.

One embodiment of the apparatus is shown in Fig. 1. Fig. 1 is a top view and Fig. 2 is a front view of a single waveguide plasma sterilizer embodiment of this invention. The plasma sterilizer has a plasma generator 2 and a sterilizing chamber 4. The plasma generator 2 comprises an electromagnetic field generator such as a magnetron 6 and a waveguide 8 which directs the electromagnetic field. The plasma source gases are directed into plasma generating and delivering tubes 10, 12, and 14 by feeder tubes from gas delivery tubes 16, 18 and 20 leading from the control valve complex 22. Individual gases are fed from the pressured gas sources (not shown) by inlet lines 24, 25 and 26. The operation of the control valves in valve complex 22 is controlled by the central processing unit (CPU) 28 by standard procedures. The control valves and CPU can be any of the conventional, standard devices used for gas flow control in plasma generating equipment.

The sterilizing chamber 4 comprises top plate 30, side plates 32 and 34, bottom plate 36, back plate 37 and front sealing door 38 through which articles or materials to be sterilized are placed in the chamber. The plates are attached together in a sealed relationship to form a vacuum chamber, such as by welding. The door 38 is secured in a sealed relationship with the sterilizing chamber. It is hinged at the top, side or bottom with conventional hinge pins (structure not shown) to swing against abutting surfaces and an O-ring seal 40 (Fig. 3) of the side, top and bottom plates, where the pressure difference between the internal chamber vacuum pressure and the surrounding atmospheric pressure holds it tightly in place.

The plates and door can be made of any material having the strength required to withstand the external atmospheric pressure when the chamber is evacuated. Stainless steel or aluminum plates and door are preferred. The internal surface material of the chamber is critical and greatly affects the number of killing species available in the chamber. An optimum material is pure (98%) aluminum which can be applied either as a liner or as a flame-sprayed coating on all internal walls of the stainless steel chamber. An alternat material is nickel.

Antimicrobial additives are added as a liquid or

form a vapor, or sufficient hydrogen peroxide vapor is introduced to produce a vapor having a concentration of 2 mg/L hydrogen peroxide. If peracetic acid pretreatment is to be combined with hydrogen peroxide pretreatment, peracetic acid, 1 ml, in the form of a 10 wt.% solution is admitted into the chamber to form a vapor, or sufficient peracetic acid vapor is introduced to produce a vapor, having a concentration of 2 mg/L peracetic acid.

3. The hydrogen peroxide and optional peracetic acid vapor exposure is continued for a time sufficient to permit full penetration of the diffusible articles, for example from 5 to 120 minutes. An exposure of from 5 to 15 minutes is usually sufficient.

4. The chamber is evacuated to 0.1 torr.

5. Process gases are admitted to the plasma chamber, preferably at a flow rate of up to 5 liters per minute, and optimally from 3 to 4 liters per minute.

6. The magnetron is energized to create the plasma, and the plasma products flow into the sterilizing chamber.

7. The plasma treatment is continued for from 5 to 30 minutes and preferably from 5 to 10 minutes.

8. The magnetron is deactivated and the process gas flow to the plasma chamber terminated.

9. Steps 1-8 are repeated until sterilization is complete and all spores are killed. Hydrogen peroxide and peracetic acid treatments can be alternated so that the pretreatment is limited to either one for a particular cycle repetition.

10. The isolation valve between the pump and chamber is closed, and the chamber is vented to the atmosphere. The sterilizing chamber can be pumped down and partially vented to remove acidic vapors before being fully vented to the atmosphere.

The above method sterilizes effectively in less time than is required using either plasma or hydrogen peroxide alone. Furthermore, it is effective for sterilizing all materials, while plasma and peracids, alone, have limited ability.

Claims

1. A process for plasma sterilization comprising pretreating an article to b sterilized with hydrogen peroxide and a peracid antimicrobial agent for a time sufficient to expose all surfaces of the article to the hydrogen peroxide and peracid, and then exposing the article to a plasma g nerated from gases selected from th group consisting essentially f argon, helium, nitrog n, oxygen, hydrogen and mixtur s thereof, the xposure to the plasma being carried out at a pressure of from 0.1 to 10 torr and a chamber temperature of less than 80° C for a time period sufficient to effect sterilization.

2. The process of Claim 1 wherein the peracid antimicrobial agent is a member selected from the group consisting of saturated and unsaturated peralkanoic acids having from 1 to 8 carbon atoms and halogenated derivatives thereof.

3. The process of claim 2 wherein the peracid antimicrobial agent is peracetic acid.

4. The process of Claim 3 wherein the peracetic acid is a vapor.

5. The process of Claim 4 wherein the pretreatment is continued for from 5 to 15 minutes in a partial vacuum.

6. The process of Claim 1 wherein the plasma is produced in a plasma generator and is fed therefrom to a sterilizing chamber, and the article to be sterilized is located in the sterilizing chamber.

7. The process of Claim 6 wherein the peracid antimicrobial agent vapor is introduced into the sterilizing chamber to expose the article located therein to said pretreatment.

8. The process of Claim 7 wherein, after said pretreatment, the pressure in the sterilizing chamber is reduced to a pressure not exceeding 10 torr, and the plasma is thereafter introduced into the sterilizing chamber.

9. The process of Claim 1 wherein the plasma is generated from a gas mixture consisting essentially of argon, helium, nitrogen or mixtures thereof; from 1 to 21 % (v/v) oxygen; and from 1 to 20 % (v/v) hydrogen.

10. The process of Claim 9 wherein the gas plasma is generated from a gas mixture containing from 1 to 10 % (v/v) oxygen and from 3 to 7 % (v/v) hydrogen.

11. The process f Claim 1 wherein th article is enclosed in a porous container, and the container is surrounded by the gas plasma during the treatm nt.

12. The process f Claim 11 wherein the p rous container comprises a carbohydrate composi-

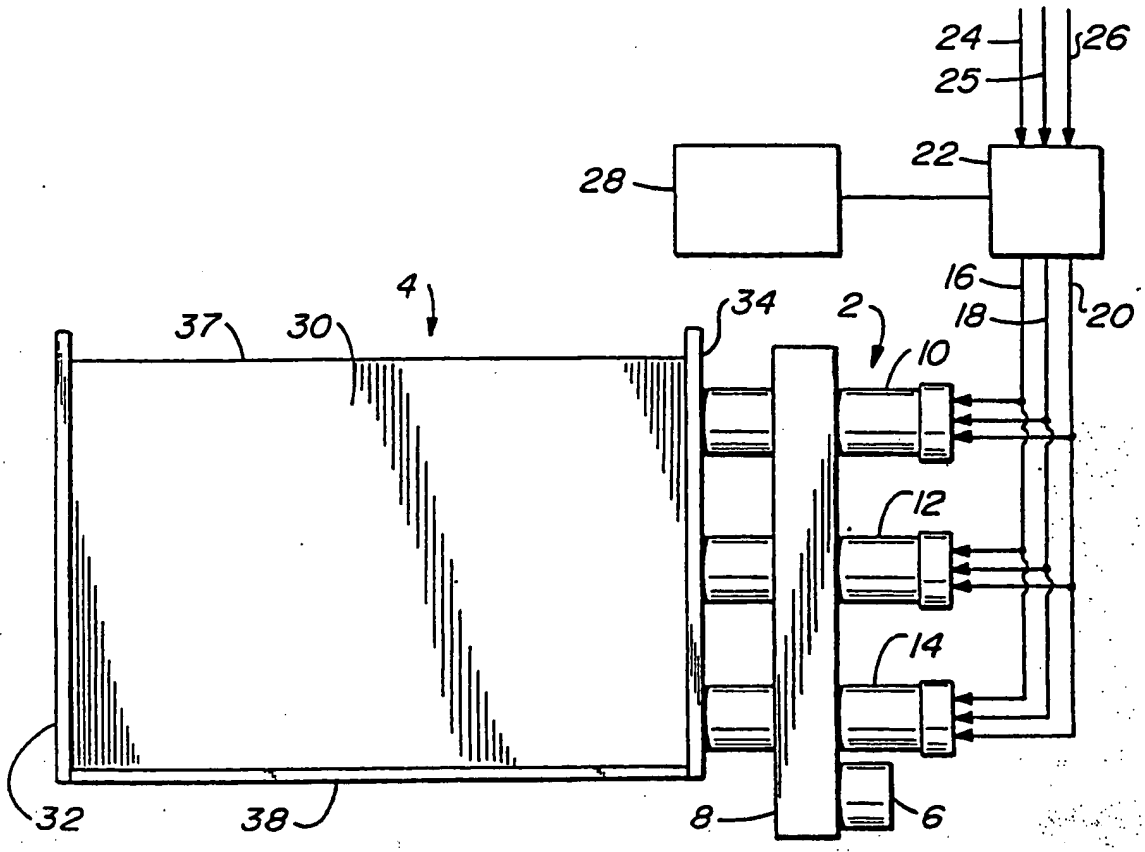
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FIG._1

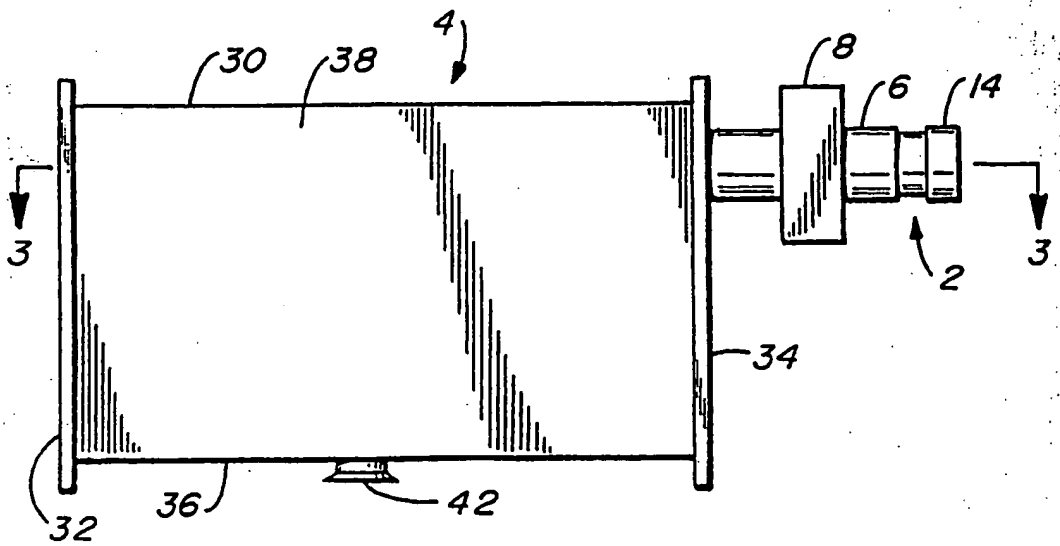
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FIG._2

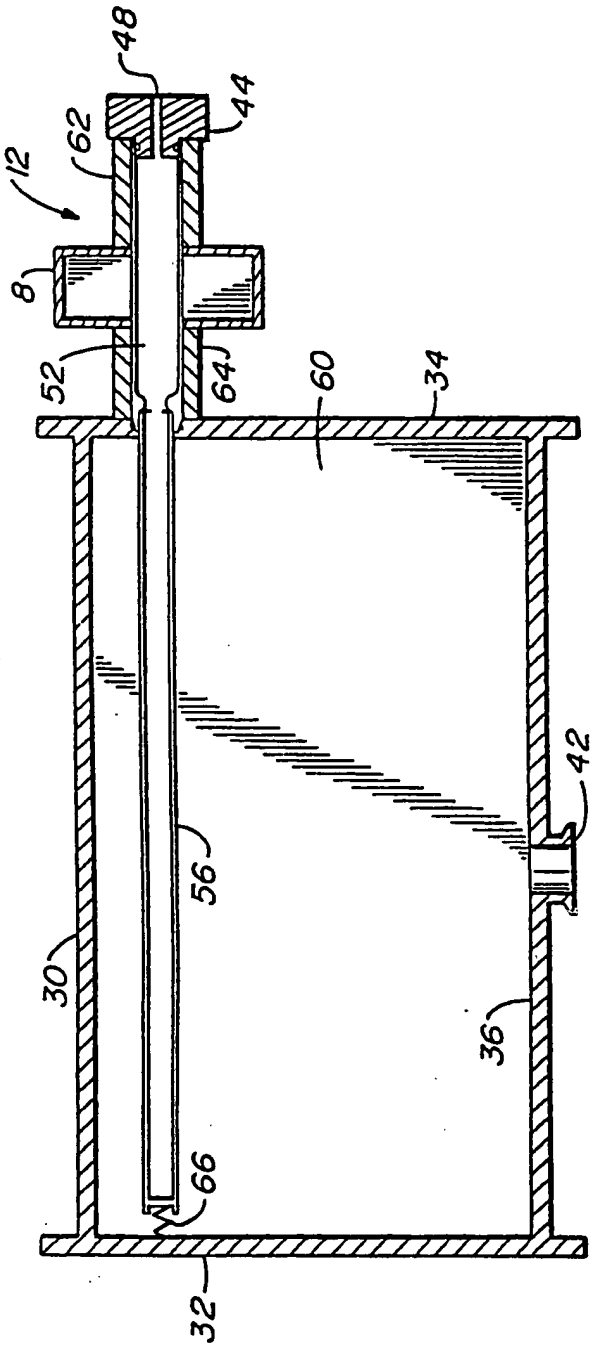

FIG._4

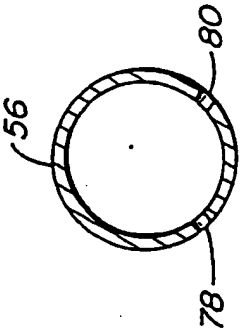

FIG._7

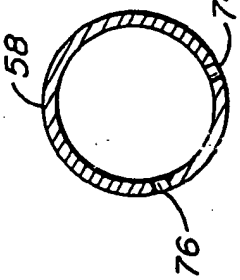

FIG._6

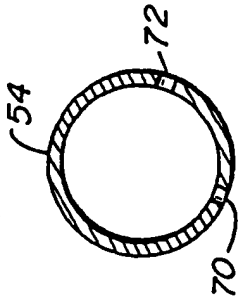

FIG._5